MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE OF SOILS BY ALTERNATE METHOD D PROCTOR

(A Modification of AASHTO Designation T 99)

SCOPE

1. (a) This test method describes the procedure for determining the maximum dry density and optimum moisture content for a soil by the Alternate Method D Proctor Method.

(b) Alternate Method D may be used for all maximum dry density and optimum moisture content determinations except for volcanic cinders or light porous material on which the specific gravity cannot be determined with consistency or when the moisture absorption for the coarse aggregate is greater than 4.0%.

(c) Alternate Method D may be used except when greater than 40% of the material is retained on the 3/4 inch sieve.

(d) An example is provided in Figure 3 for the calculations and determinations referenced herein.

(e) This test method may involve hazardous materials, operations, and equipment. This test method does not purport to address all of the safety problems associated with its use. It is the responsibility of whomever uses this test method to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

APPARATUS

2. The apparatus shall consist of the following:

(a) 6 inch proctor mold having a capacity of approximately 1/13.33 cubic foot, with an internal diameter of 6.000 plus 0.039 or minus 0.026 inches and a height of 4.584 plus 0.005 or minus 0.008 inches. The mold shall have a nominal wall thickness of 1/4 inch. It shall be equipped with an extension collar approximately 2-3/8 inches high. A baseplate as shown in Figure 1 shall be provided.

(b)   A hand or mechanical rammer weighing 5.50 ± 0.02 pounds, having a flat face, and equipped with a suitable arrangement to control the height of drop to a free fall of 12 ± 0.06 (1/16) inches above the elevation of the soil. The hand rammer face shall be circular with a diameter of 2.000 plus 0.010 or minus 0.015 inches. The mechanical rammer face shall have the shape of a piece of pie, with a radius of approximately 3 inches, and having an area of 3.134 ± 0.039 square inches. If a mechanical apparatus is used, it must be monitored through the ADOT proficiency sample program and maintain a rating of 3 or better based on the results of testing ADOT and AMRL proficiciency samples.

(c)   Hardened-steel straightedge, at least 10 inches in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.01 inch per 10 inches (0.1 percent) of length with the portion used for trimming the soil.

(d)   Scale or balance capable of measuring the maximum weight to be determined, accurate to at least one gram.

(e)   Scale or balance capable of measuring the maximum weight to be determined, accurate to at least 0.1 gram.

(f)   Oven capable of maintaining a temperature of $230^\circ \pm 9^\circ$ F $(110^\circ \pm 5^\circ$ C).

(g)   3/4 inch and 3 inch sieves conforming to the requirements of AASHTO M 92.

(h)   Miscellaneous mixing tools and pans.

(i)   Sample Extruder (optional) consisting of a jack, lever, frame, or other device for extruding the compacted sample from the mold.

CALIBRATION OF MOLD

3.   Molds shall be calibrated in accordance with APPENDIX A of Arizona Test Method 225.

SAMPLE

4.   The sample shall be prepared as follows:

(a)   Enough soil material shall be provided from the field to make five compacted specimens. A minimum sample size of 45,000 grams (approximately 100 lbs.) is normally required.

(b)   If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a slow fan or other drying apparatus such that the temperature of the sample does not exceed 140º F.

(c)   Thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

(d)   Weigh out an approximate 45,000 gram sample of representative soil. Record the weight of the sample, and sieve the material over a 3/4 inch sieve. If the percentage of coarse aggregate or rock retained on the 3/4 inch sieve is not already known from gradation testing, save any material retained on the 3/4 inch sieve and weigh. Calculate the percent of coarse aggregate or rock particles retained on the 3/4 inch sieve according to the following equation:

$$PR3/4 = \frac{WR3/4}{WT} \times 100$$

Where: PR3/4   =   Percentage of coarse aggregate or rock
                    particles retained on the 3/4 inch sieve

WR3/4   =   Weight of coarse aggregate or rock
              particles retained on the 3/4 inch sieve

WT   =   Total weight of material sieved

(e)   If "PR3/4" is greater than 40%, then too much rock is present to allow for a reasonable maximum dry density determination If "PR3/4" is less than or equal to 40%, blend material passing the 3/4 inch sieve thoroughly and proceed to Section 5 of this test method.   If a specific gravity and absorption determination, in accordance with AASHTO T 85, is to be made for the plus 3/4 inch material, save an adequate amount of this material, otherwise, discard it.

PROCEDURE

5. Procedure to be used is as follows:

(a)   From the thoroughly blended passing 3/4 inch material from paragraph 4(e), split out 5 representative approximate 5000 gram samples.

(b)   Select one sample and thoroughly mix with sufficient water to dampen it to approximately three percentage points below optimum moisture content.

NOTE: If desired, an additional three samples may be mixed at this time with approximate moisture contents of 1% below optimum, 1% over optimum, and 3% over optimum. The moisture in each of these samples shall be retained by covering with a damp cloth or being sealed in air tight containers until they are compacted. One of the five samples should be retained for future use since it is necessary to have at least two points defined on each side of the moisture-density curve.

(c)   Heavy clay soils or materials which tend to break down, or those in which it is difficult to incorporate water, shall require approximately 12 hours for uniform moisture absorption to be achieved. This shall be accomplished by preparing separate samples for each increment of water to be added, and then placing and sealing these samples in air tight containers for the 12-hour period.

(d)   Form a specimen by compacting the prepared soil in the six inch mold (with extension collar attached) in three equal layers to give a total compacted depth of about 5 inches. Compact each layer with 56 uniformly distributed blows from the rammer, dropping free from a height of 12 inches. While each layer is being compacted, the remainder of material shall be in a pan covered by a damp cloth. During compaction, the mold shall rest firmly on a dense, uniform, rigid and stable foundation.

NOTE: Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: A block of concrete, weighing not less than 200 lbs., supported by a stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges, and pavements.

(e)   When compacting granular, free-draining materials, at moisture contents which are at or above optimum, the mold shall be prepared by first sealing the bottom of the mold with waterproofing grease. All excess grease shall be wiped from the mold and baseplate.

(f)   Following compaction, carefully remove the extension collar. It may be necessary to use a follower to retain the soil in the mold while removing the collar to prevent damage or disturbance of the soil below the top of the mold. Carefully trim the compacted soil even with the top of the mold by means of the straightedge. If any voids are created during trimming, these shall be filled with fine material and smoothed off. Determine the weight of compacted specimen and mold. Determine the wet density, "WD", of the compacted soil by the following:

$$WD = \frac{M1 - M2}{VM \times 453.6 \text{ (grams/lb.)}}$$

Where: WD = Wet density of compacted soil, lb./cu. ft.
         M1 = Weight of compacted specimen and mold, grams
         M2 = Weight of the mold, grams
         VM = Volume of the mold, cu. ft. (See Section 3
              of this procedure.)

(g)   The estimated dry density, "ED", of the compacted soil may be calculated and recorded to the nearest 0.1 lb./cu. ft. as follows:

$$ED = \frac{WD}{(\text{Approx. \% of water added}) + 100} \times 100$$

Where: ED = Estimated dry density of compacted soil,
              lb./cu. ft.
         WD = Wet density of compacted soil, lb./cu. ft.

NOTE: These estimated densities are approximate only and will
        be corrected when final moisture results are obtained.

(h)   The estimated dry density is useful in deciding how much water to add in later trial batches, if the procedure described in the note following paragraph 5(b), for initially preparing three additional samples with varing moisture contents is not utilized. By carefully observing the estimated dry density of the compacted samples, the operator should be able to vary the moisture content as the test proceeds so that when the final moisture-density results are plotted, a curve will result that rises to a peak and then falls away.

(i)   Remove the material from the mold and slice vertically through the center. Take a representative minimum 600 gram sample from the full length and width of one of the cut faces. Weigh immediately, and dry to a constant weight in an oven at $230^\circ \pm 9^\circ$ F ($110^\circ \pm 5^\circ$ C) to determine the moisture content in accordance with AASHTO T 265. Record the weight of wet soil to the nearest 0.1 gram as "WW", and record the weight of oven dry soil to the nearest 0.1 gram as "DW".

(j)   For granular, free-draining materials, the moisture content shall be determined using the entire compacted proctor specimen. Determine the weight of wet soil, "WW", by subtracting the weight of the mold, "M2", from the weight of compacted specimen and mold, "M1". Record the weight of wet soil, "WW", and the weight of oven dry soil, "DW", to at least the nearest gram. All clinging material shall be removed from the inside of the mold and included with the specimen. To facilitate drying, the specimen may be broken up and spread out in a large pan, being careful to not lose any soil particles.

(k)   Select another of the samples which was split in paragraph 5(a), and if not already done, thoroughly mix with water in sufficient amount to increase the moisture content by approximately two percentage points.

(l)   Repeat the procedure in paragraphs 5(c) through 5(j) for the sample at each moisture content, as necessary to establish a moisture-density curve which rises to a peak and then falls away.

CALCULATIONS

6.   Calculate the percent moisture and dry density for each of the compacted soil samples as follows:

(a)   Calculate percent moisture and record to the nearest 0.1 percent by the following:

$$\% \text{ Moisture} = \frac{WW - DW}{DW} \times 100$$

Where: WW = weight of wet soil, grams
         DW = weight of oven dry soil, grams

(b)   Calculate dry density and record to the nearest 0.1 lb./cu. ft. by the following:

$$DD = \frac{WD}{\% \text{ Moisture} + 100} \times 100$$

Where: DD = Dry density of compacted soil, lb./cu. ft.
WD = Wet density of compacted soil, lb./cu. ft.

MOISTURE-DENSITY RELATIONSHIP

7.   The percent moisture and corresponding dry density for each of the compacted soil specimens shall be plotted on the graph provided on the proctor density test form shown in Figure 2. For a good plot, the majority of the graph is utilized. Normally, three increments on the horizontal axis shall equal one percent of moisture, and three increments on the vertical axis shall equal one lb./cu. ft. of dry density. If another number of increments other than three is utilized, the number of increments for one percent moisture and one lb./cu. ft. dry density shall always be the same.

       (a)   On each side of the maximum density curve, at least two points should be utilized to form two straight lines. The intersection point of these two lines defines the peak point of the density-moisture content relationship, or the maximum density and optimium moisture content for the soil. In general it will be found that higher unit mass soils assume steeper slopes with high maximum dry densities at low optimum moisture contents, while the lower unit mass soils assume flatter, more gently sloped lines with high optimum moisture contents and low maximum dry densities. Figure 4 gives examples of moisture-density plots which show the different slopes associated with different maximum dry density ranges.

       (b)   Optimum moisture content - The percent moisture content corresponding to the peak (intersection point of the two lines) of the moisture-density curve shall be termed the "optimum moisture content", and shall be reported as "OM" to the nearest 0.1 percent.

       (c)   Maximum dry density - The dry density at optimum moisture content corresponding to the peak (intersection point of the two lines) of the moisture-density curve shall be termed the "maximum dry density", and shall be reported as "MD" to the nearest 0.1 lb./cu. ft.

NOTE: The optimum moisture and maximum dry density determinations above are for the material passing the 3/4 inch sieve. When testing field samples for comparison to proctor optimum moisture and maximum dry density, a correction to the proctor optimum moisture and maximum dry density must be made, in accordance with ARIZ 227, for the percent rock which the field sample contains.

REPORT

8.   Record the moisture and density data on the laboratory test form along with the laboratory number, material source and type, and other information required. A blank laboratory test form is provided in Figure 2.
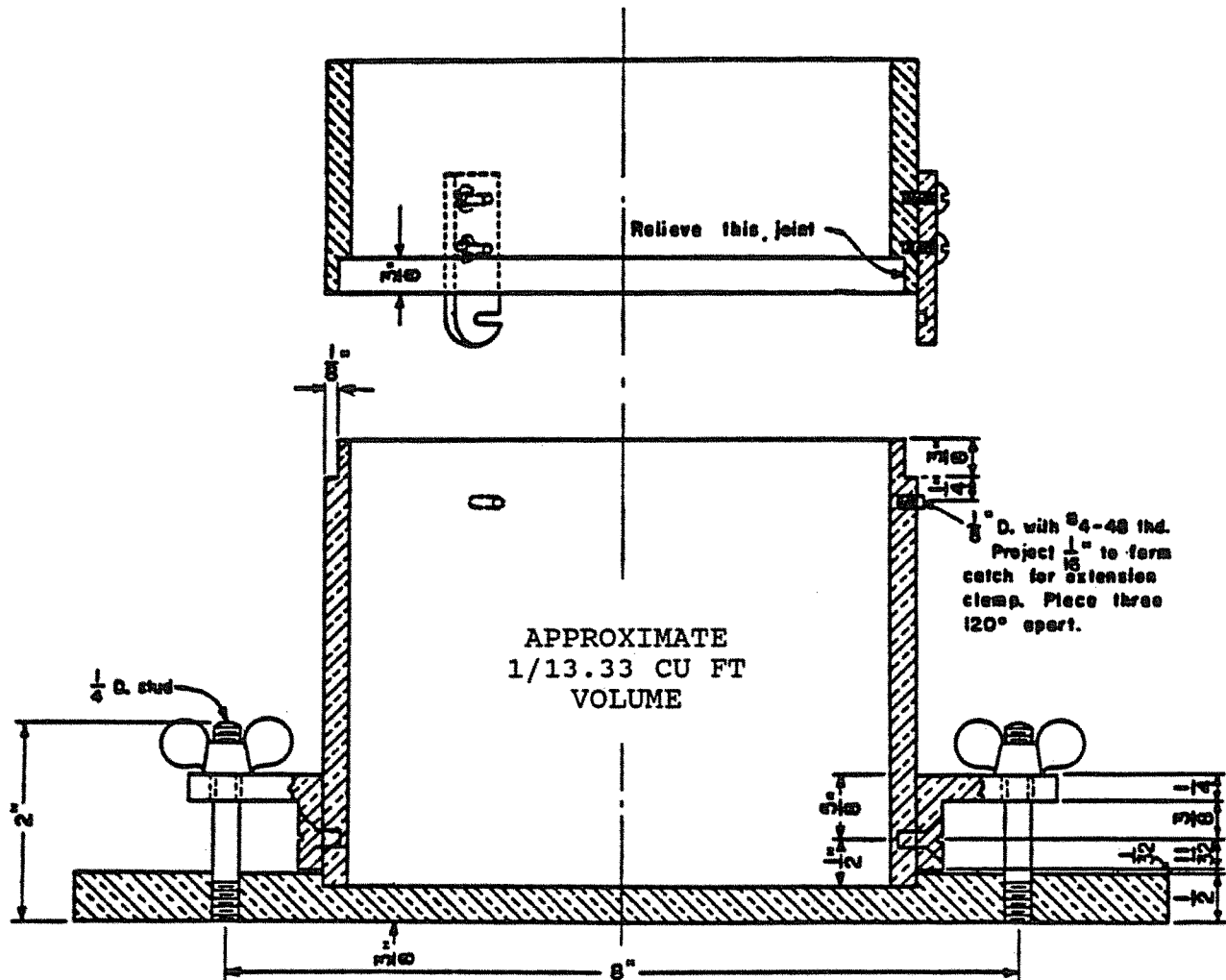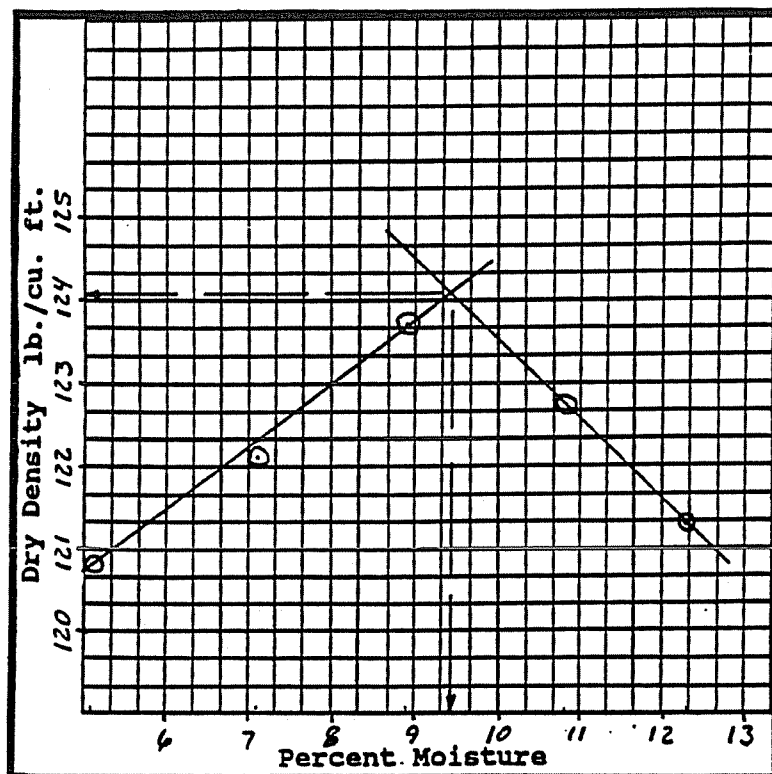
CYLINDRICAL MOLD, COLLAR
AND BASEPLATE
(6 INCH MOLD)

FIGURE 1

Arizona Department of Transportation
METHOD A OR ALTERNATE METHOD D PROCTOR DENSITY
(Arizona Test Method 225 or 245)

Project No.: _____   Lab. No: _____   Rec'd Date: _____
Source and Type of Material: _____
Proctor Method Used: Method A _____ or Alternate Method D _____
Test Operator and Date: _____
Supervisor and Date: _____

Weight of Mold = M2 =   grams   Volume of Mold = VM =   cu ft   a = VM x 453.6 =

b	M1	c	WD	ED	Moisture Determination				DD
					WW	DW	d	e	
Approx % of Water Added	Wt. of Sample and Mold	Wet Wt. of Sample M1 - M2	Wet Density lb/cu ft $\frac{c}{a}$	Est. Dry Density $\frac{WD \times 100}{b + 100}$	Wet Wt. of Moisture Sample	Dry Wt. of Moisture Sample	Wt. of Water WW - DW	Percent Moisture $\frac{d \times 100}{DW}$	Dry Density lb/cu ft $\frac{WD \times 100}{e + 100}$

__METHOD A__

WT = _____   WR4 = _____

PR4 = $\frac{WR4}{WT}$ x 100 = _____ %

__ALTERNATE METHOD D__

WT = _____   WR3/4 = _____

PR3/4 = $\frac{WR3/4}{WT}$ x 100 = _____ %

Coarse Aggregate
Bulk Oven Dry
Specific Gravity: _____

Coarse Aggregate
Absorption: _____ %

OPTIMUM MOISTURE
CONTENT = OM = _____ %

MAXIMUM DRY DENSITY
(lb./cu. ft.) = MD = _____

Dry Density lb./cu. ft.

Percent Moisture

REMARKS: _____

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FIGURE 2

Arizona Department of Transportation
METHOD A OR ALTERNATE METHOD D PROCTOR DENSITY
(Arizona Test Method 225 or 245)

Project No.: _____ Lab. No: _____ Rec'd Date: _____
Source and Type of Material: _____
Proctor Method Used: Method A _____ or Alternate Method D ___✓___
Test Operator and Date: _____
Supervisor and Date: _____

Weight of Mold = M2 = **2840** grams | Volume of Mold = VM = **0.0744** cu ft | a = VM x 453.6 = **33.7478**

b	M1	c	WD	ED	Moisture Determination				DD
					WW	DW	d	e	
Approx % of Water Added	Wt. of Sample and Mold	Wet Wt. of Sample $M1 - M2$	Wet Density lb/cu ft $\frac{c}{a}$	Est. Dry Density $\frac{WD \times 100}{b + 100}$	Wet Wt. of Moisture Sample	Dry Wt. of Moisture Sample	Wt. of Water $WW - DW$	Percent Moisture $\frac{d \times 100}{DW}$	Dry Density lb/cu ft $\frac{WD \times 100}{e + 100}$
7	7180	4340	128.6	120.2	655.5	613.8	41.7	6.8	120.4
9	7376	4536	134.4	123.3	685.3	628.7	56.6	9.0	123.3
11	7474	4634	137.3	123.7	658.4	592.1	66.3	11.2	123.5
13	7457	4617	136.8	121.1	645.9	572.1	73.8	12.9	121.2

METHOD A

WT = _____ WR4 = _____

$PR4 = \dfrac{WR4}{WT} \times 100 = $ _____ %

ALTERNATE METHOD D

WT = **48780** WR3/4 = **17951**

$PR3/4 = \dfrac{WR3/4}{WT} \times 100 = $ **37** %

Coarse Aggregate
Bulk Oven Dry
Specific Gravity: **2.631**

Coarse Aggregate
Absorption: **2.28** %

OPTIMUM MOISTURE
CONTENT = OM = **10.2** %

MAXIMUM DRY DENSITY
(lb./cu. ft.) = MD = **124.8**

REMARKS: _____

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FIGURE 3

AGGREGATE BASE COURSE

% Moisture	Dry Density
5.1	120.8
7.1	122.1
8.9	123.7
10.8	122.7
12.3	121.3

Maximum Density = 124.1 lb/cu ft
Optimum Moisture = 9.4%

**SILTY SAND
AND GRAVEL**

% Moisture	Dry Density
7.2	127.0
8.1	129.6
9.4	127.9
10.1	126.6

Maximum Density = 130.0 lb/cu ft
Optimum Moisture = 8.3%
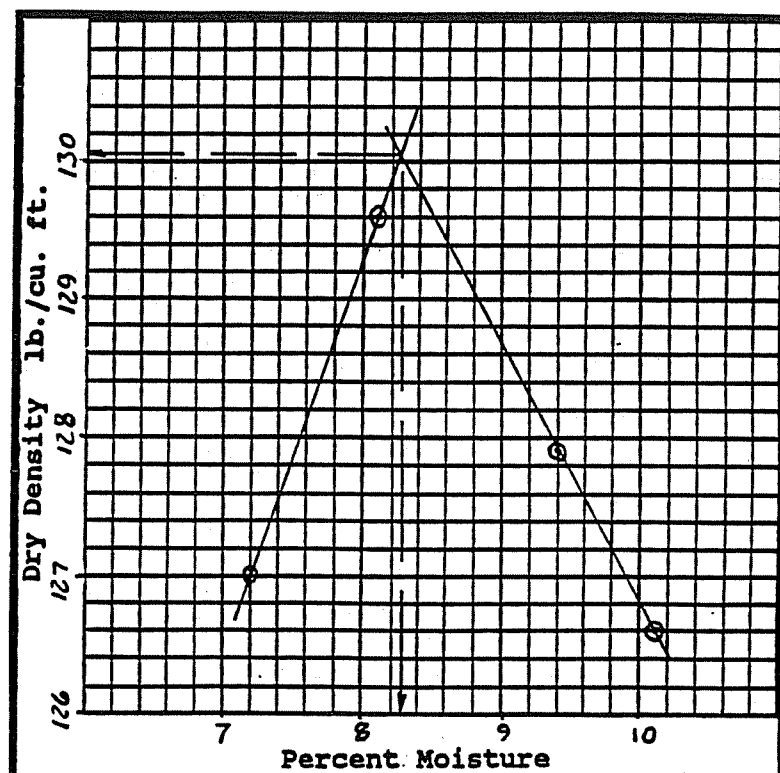
EXAMPLE PROCTOR DENSITY CURVES

FIGURE 4